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Reveiw Article

Biodegradation of Marine Pollutants by Microorganisms: A Bibliometric Analysis

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ABSTRACT

The oceans, as a large area of the planet, are of great importance to the biological status of organisms. They are contaminated with different compounds that are dangerous to health conditions. Biodegradation is one way to reduce pollution. Therefore the current review aimed to this bibliometric analysis. Data were collected from published articles in Scopus and Clarivate Analytics Web of Science databases between 1985 and April 2021, and then Scopus documents were examined using VOS viewer and Bibliometrix-package due to their larger number. Analysis was performed for the number of publications per year, document types, sources, keywords, authors, organizations, and countries. The results showed a growing trend in publishing documents from 2010 to 2022. The two keywords biodegradation and bioremediation grew more.

1. Introduction

Over the past few years, the oceans have been used to dispose of waste and litter. Accumulation and stability of these substances in water cause pollution in the ecosystem. Types of marine pollution include crude oil[1], plastic[2], and other chemical pollution[3].

Annually, large volumes of crude oil and its products are transported through waterways, which can lead to ocean pollution. Oil pollution can reduce biodiversity, that various aspects of this issue can be traumatic[4]. Despite the widespread use of plastics in human life, their disposal in the oceans causes many problems that are harmful to health[2]. Environmental microbial flora can degrade plastic compounds. Some researcher work on cynobacteria that ability to biodegradation of crude oil and thus research on cyanobacteria has been promising[5].

Bioremediation is a process in which microorganisms are used to eliminate or reduce environmental pollution. Diverse bioremediation procedures based on microbial metabolisms, such as natural attention, bioaugmentation and biostimulation was designed and created[6]. The biodegradation quality is affected by different factors, including bacterial physiology[7], type of pollutant[8] and environmental conditions[9].

So far, bacteria with the ability to bioremediate have been isolated and identified from different sources such as soft corals, sponges, marine sediments. Ansari et al. introducded the bacterial isolates that had the greatest ability to decompose crude oil from the genera *Cobetia*, *Shewanella*, *Alcanivorax*, and *Cellulosimicrobium* by studying bacteria with the bioremediation ability of Persian Gulf corals in Iran[10]. Ados Santos et al. also performed a mixture of coral prebiotic bacteria intending to degrade the water-soluble part of the oil[11]. The results were not only encouraging for degradation but even promising for improving coral health. Ferrante et al. reported the high capacity of bioaccumulation of Cu in *Chondrilla nucula* sponge, which can be used as bioremediation in polluted coastal areas[12]. In another study, the biodegradability of *Spheciospongia vesparium* sea sponge for dissolved organic matter was investigated[13]. In a study on marine sedimentary origin, resistant strains, such as *Vibrio*, *Pseudoalteromonas*, and *Agarivorans* were identified in contaminated areas. Their results explained that bacterial isolates with ability to tolerate or resistant to polycyclic aromatic hydrocarbon and heavy metals contaminants were present in marine

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sediments that can be a hopeful source for bioaugmentation processes[8].

Accordingly, there are reports of the ability of bacteria to biodegrade in marine environments[14-16]. The purpose of this study was to perform a bibliometric analysis on this subject. Also, review of new finding in this scope of research is another aim of this study.

2. Materials and Methods

Data collection was performed on two comprehensive databases of Clarivate Analytics Web of Science (WoS) and Scopus on April 3, 2021. The date of the last update for the WoS website is April 2, 2021. A total of 952 documents published from 1953 to 2021 were retrieved from Scopus database. and to identify with the WoS database, data were collected from both databases during the period 1985 to 2021 (120 article). The search terms used and other analytics factors in each of the databases are arranged in Table 1.

Because the number of documents published in Scopus was slightly higher than in WoS, further studies were conducted on documents in the Scopus database. In this bibliometric analysis, keywords, authors, journals, and countries were examined using VOS viewer v.1.6.16[17] and Bibliometrix-package[18] in Rstudio software, and the results were recorded.

Contaminants, such as crude oil and other chemical compounds, are present in marine ecosystems. In this analysis, the type of pollution was not the target, and non-separation of the pollution type is one of the limitations of this study.

Table 1. Search terms used and specification documents (1985-2021)

	WoS	Scopus
Search terms	TITLE: “Bioaccumulation” OR “Bioaugmentation” OR “Bioavailability” OR “Biodegradation” OR “Bioremediation” OR “Biosorption” OR “Biostimulation” OR “Biosurfactant” OR “Biotransformation” OR “Degradation” OR “Detoxification” AND TOPIC: “marine” OR “sea” OR “ocean” AND TITLE: “microb*” OR “bacter*”	TITLE: “Bioaccumulation” OR “Bioaugmentation” OR “Bioavailability” OR “Biodegradation” OR “Bioremediation” OR “Biosorption” OR “Biostimulation” OR “Biosurfactant” OR “Biotransformation” OR “Degradation” OR “Detoxification” AND TITLE-ABS-KEY “marine” OR “sea” OR “ocean” AND TITLE “microb*” OR “bacter*”
Results (Total)	861	888
Open-Access	294	298
OA (%)	34/14	33/55
Average Citations Per Item	27/54	-
Average years from publication	-	10/3
Average citations per documents	-	26/02
Average citations per year per doc	-	2/479

3. Result and Discussion

In the continuation of this study, the results are mentioned and discussed.

3.1. Analysis of publication years

As shown in Figure 1, in general, the subject under analysis had a growing trend over the years in both databases. However, in some years, the number of documents has decreased, compared to last year. It may be researcher shift to new scopes. Reducing the number of documents in 2021 because that information is collected in April 2021 and probably until the end of 2021 this amount will increase.

It should be noted that 10 million gallons of oil were discharged into the sea in Alaska when Exxon Valdez ran aground on March 24, 1989[19]. This event and the subsequent damage to marine ecosystems may have contributed to the growth of the subject matter in the coming years.

In Figure 2, the average article citations per year is

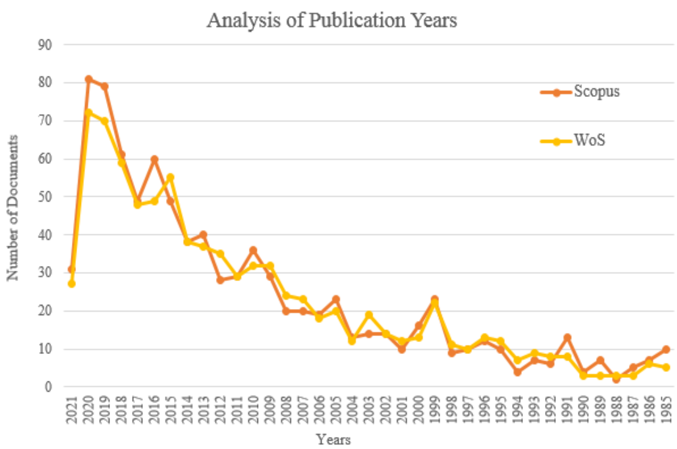

Figure 1. Analysis of publication years

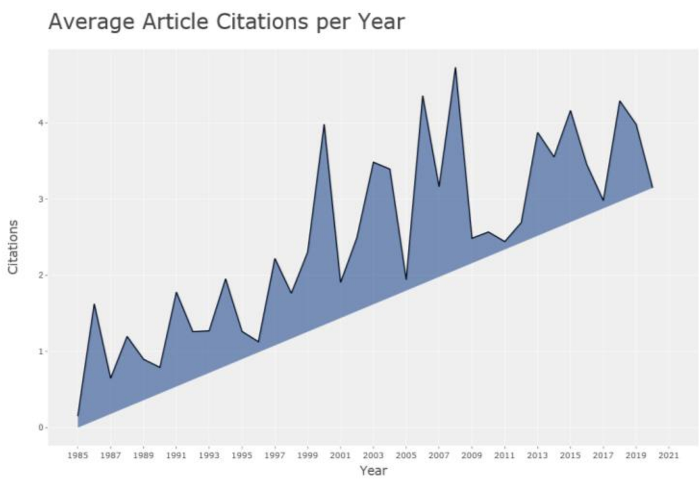

Figure 2. Average article citations per year (Scopus)

Table 2. Most global cited documents

Paper	Source	TC	TC per year	Reference
Bioremediation of high molecular weight polycyclic aromatic hydrocarbons: a review of the microbial degradation of benzo[a]pyrene	International Biodeterioration & Biodegradation	802	36	46
Plastics: Environmental and Biotechnological Perspectives on Microbial Degradation	Applied and Environmental Microbiology	66	22	47
Microbial Ecotoxicology of Marine Plastic Debris: A Review on Colonization and Biodegradation by the "Plastisphere"	Frontiers in Microbiology	64	21	48
Degradation of plastics and plastic-degrading bacteria in cold marine habitats	Applied Microbiology and Biotechnology	75	18	49
Recent studies in microbial degradation of petroleum hydrocarbons in hypersaline environments	Frontiers in Microbiology 2014	146	18	50
Marine methane paradox explained by bacterial degradation of dissolved organic matter	Nature Geoscience	104	17	51
Marine Microbial Assemblages on Microplastics: Diversity, Adaptation, and Role in Degradation	Annual Review of Marine Science	34	17	52
Whole genome analysis of the marine Bacteroidetes*'Gramella forsetii'* reveals adaptations to degradation of polymeric organic matter	Environmental Microbiology	249	15	53
Biodegradation of low-density polyethylene by marine bacteria from pelagic waters, Arabian Sea, India	Marine Pollution Bulletin	126	14	54
Occurrence of endocrine disrupting compounds in aqueous environment and their bacterial degradation: A review	Critical Reviews in Environmental Science and Technology	84	14	55

TC: Total citation

plotted. As it turns out, this is an uptrend and it has increased over the years. The highest value of this metric in 2008 was 4/7. Table 2 lists 10 documents with the highest number of total citations (TC) per year.

3.2. Analysis of keywords

The abundance of keywords Plus and the author's keywords in the documents collected by the Scopus database were determined to be 6192 and 1927, respectively. The results related to the analysis of index keywords in VOS viewer software are shown in Figure 3. The analysis was performed for the minimum number of occurrences 20 of a keyword, which was classified into 4 clusters. The characteristics of each cluster in Figure 3 are recorded in Table 3. According to the purpose of this study of bibliometric analysis, two clusters included 1 and 2 with the titles of Biodegradation and Bacteria (Microorganisms) had the most items. However, the highest total link strength was determined for the five Index Keywords Article, Nonhuman, Bioremediation, Biodegradation, and Bacteria as 7173, 6492, 6224, 5997, and 5698, respectively.

Figure 4 presents the growth rate of 10 words over the years. According to this chart, although the word Biodegradation was more important than the word Bioremediation in 1989-2008, both of these words grew to the same extent in 2008-2014. Furthermore, the highest growth rate of the word Bacteria (Microorganism) is observed in 2015, after which it has slowly decreased. However, words with almost the same meaning even by a mention, such as Bacterium and Bacteria are still growing.

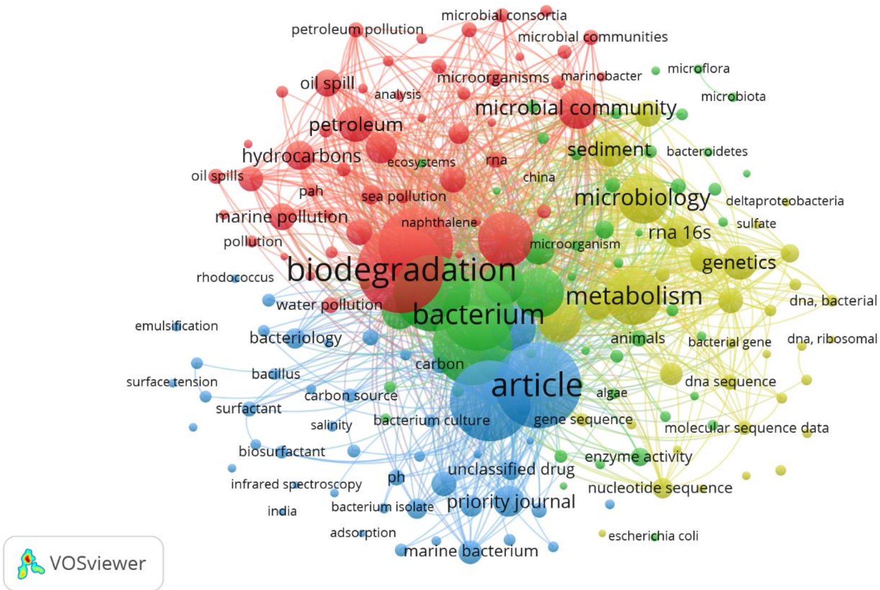

Figure 3. Index keywords analysis

Table 3. Index keyword clustering using VOS viewer

Red	Cluster 1 (51 items)	Biodegradation
Green	Cluster 2 (51 items)	Bacteria (Microorganisms)
Blue	Cluster 3 (50 items)	Article
Yellow	Cluster 4 (37 items)	Metabolism

3.3. Analysis of Document types

The types of documents published in both databases are shown graphically in Figure 5. Although the classification of document types in both databases was slightly different, most were related to articles. Regarding the Scopus database, the second rank of most documents belonged to the conference paper category. Also, review documents formed a smaller percentage compared to other types of article. Generally, this chart (Figure 5) can show the growing trend of the subject matter.

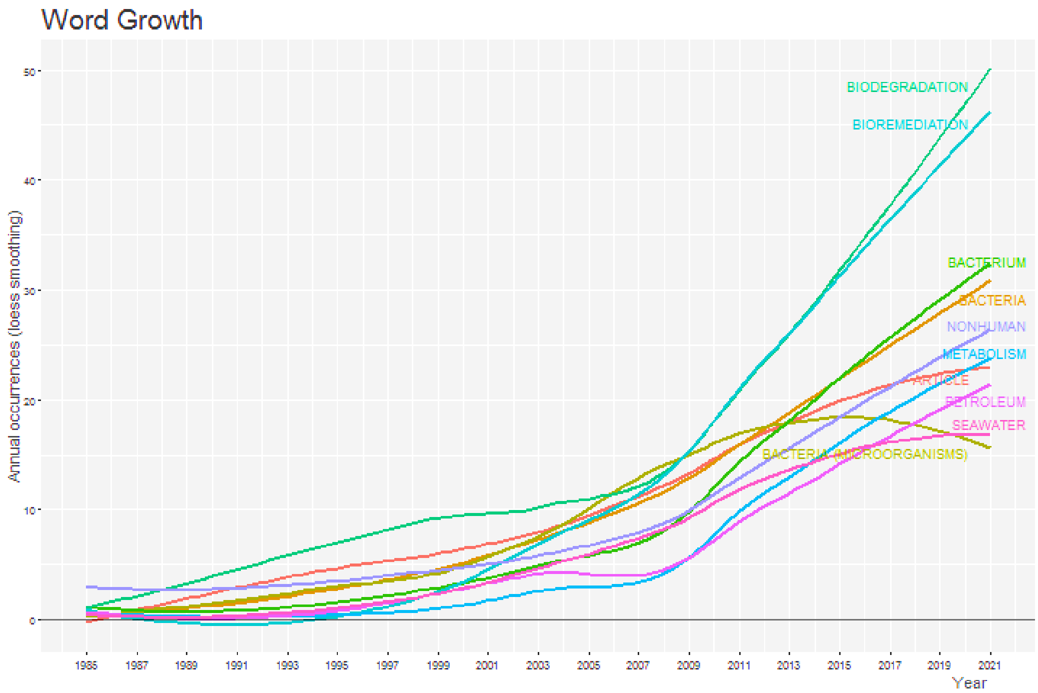

Figure 4. Word growth (Scopus)

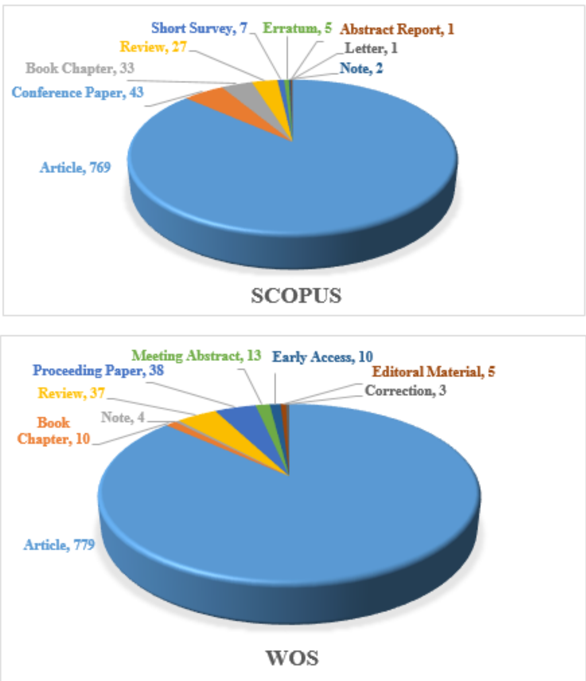

Figure 5. Types of documents in Scopus and WoS data databases

3.4. Analysis of Sources

Figure 6 shows the growth rate of 6 sources in this research topic by year. Figure 7 shows the core sources according to Bradford's law. This rule is used in bibliometric analyzes to identify major or core journals in that field of research[20-22].

However, the results of these figures, show the two sources of Marine Pollution Bulletin [23-25] and Frontiers in Microbiology[8,26-29]. The new Research, have grown significantly in recent years. The CiteScore for these two sources was 6/7 and 6/4 in 2019, respectively.

3.5. Analysis of authors

The results of the authors' general analysis based on the documents collected from Scopus are presented in Table 4. In Figure 8, each line shows the author's timeline and the size of the circle, the number of documents the author has published, which is between 1 and 5. For example, 5 documents in 2018 have been published by Brakstad OG. Furthermore, the color intensity was comparable to the total citations per year of the published records. This value varies from 0 to 27. The highest amount in 2015 for the author Cappello S was recorded at 27/286. Likewise, in Table 5 are the top ten authors listed based on the most TC per year.

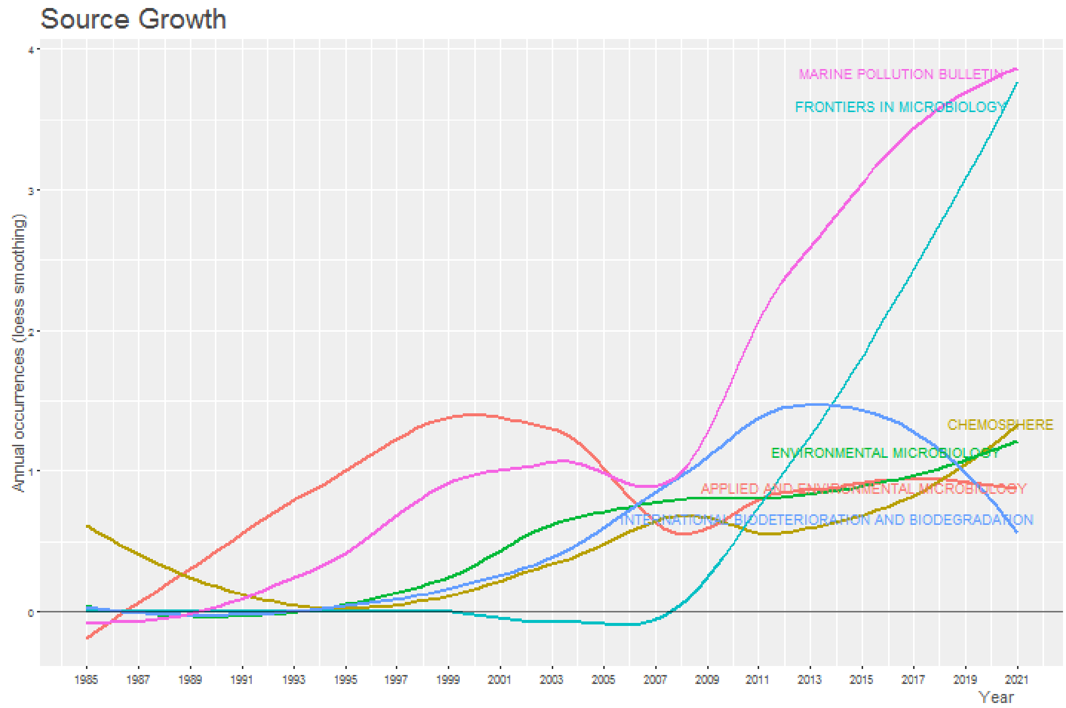

Figure 6. Growth of sources of documents collected from the Scopus database

3.6. Analysis of organizations

Organizational analysis using VOS viewer was performed based on at least three documents from each organization, each of which was listed at least three times. Of 2113 organizations, 11 were identified. Information about these 11 organizations is listed in Table 6. Additionally, the time classification of these organizations about the subject under study is shown in Figure 8.

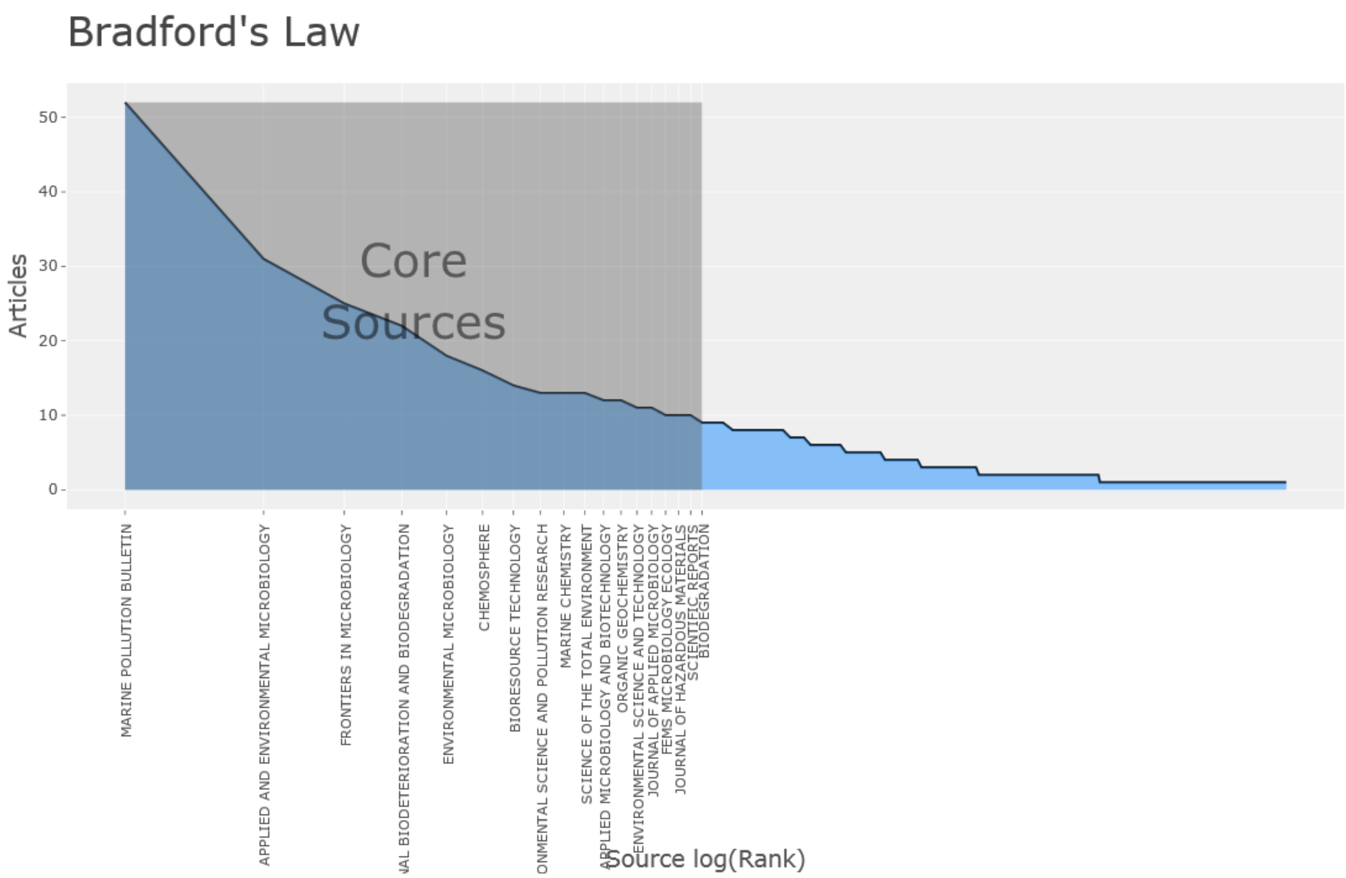

Figure 7. Core Sources

Table 4. Analysis of authors and their relationships from Scopus documents.

Authors		Authors' collaboration	
Description	**Results**	**Description**	**Result**
Authors	3319	Single-authored documents	35
Authors Appearances	4352	Documents per author	0/268
Authors of single-authored documents	34	Author per document	3/74
Authors of multi-authored documents	3285	Co-Authors per documents	4/9
		Collaboration index	3/85

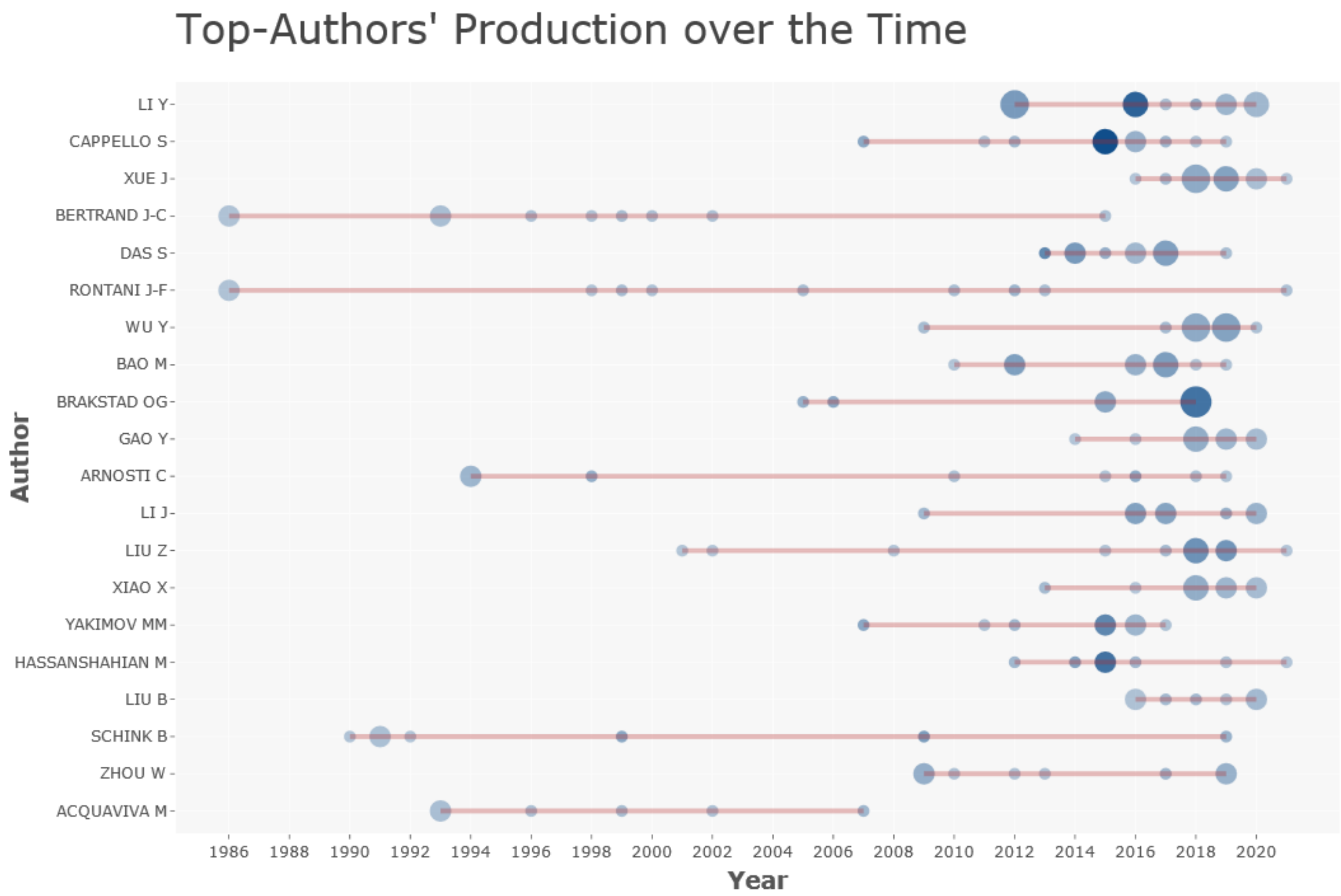

Figure 8. Top-authors' publication over the time

3.7. Analysis of countries

The results of this part of the analysis showed that 73 countries have published documents related to this issue in Scopus. First to third place were for the United States, China, and India with the number of documents 158, 137 and 105, respectively. Figure 10 shows countries with at least 10 documents published and their number is displayed. Moreover, 16 countries have published only one document and 11 documents have been classified as undefined.

Figure 11 presents the cooperation between countries on the world map. The highest level of collaboration was recorded for the USA and Germany (n= 12 cases). In this image, each red line represents a collaboration between countries, and the dark blue regions have published

Table 5. Top ten authors' publication per year

	Author	Year	TC	TC per Year
1	Cappello S	2015	191	27/286
2	Li Y	2016	135	22/500
3	Hassanshahian M	2015	133	19/000
4	Brakstad OG	2018	75	18/750
5	Yakimov MM	2015	99	14/143
6	Das S	2013	123	13/667
7	Liu Z	2018	47	11/750
8	Liu Z	2019	33	11/000
9	Das S	2014	79	9/875
0	Li Y	2012	95	9/500

Table 6. Organizations with at least 3 documents and 3 citations

Organization	Documents	Citations	Total link strength
Department of Marine Sciences, University of Georgia, Athens, GA, United States	3	31	2
Department of Microbiology, University of Georgia, Athens, GA, United States	3	62	2
Center for Geomicrobiology, Department of Bioscience, Aarhus University, Aarhus, Denmark	3	26	0
College of Chemical and Environmental Engineering, Shandong University of Science and Technology, Qingdao, Shandong, 266590, China	4	19	0
College of Marine Studies, University of Delaware, Lewes, DE 19958, United States	4	243	0
Department of Biology, Faculty of Sciences, Shahid Bahonar University of Kerman, Kerman, Iran	3	47	0
Department of Biotechnology, Indian Institute of Technology, Kharagpur, West Bengal 721302, India	3	242	0
Key Laboratory of Marine Chemistry Theory and Technology, Ministry of Education, Ocean University of China, Qingdao, 266100, China	3	20	0
Key Laboratory of Marine Chemistry Theory and Technology, Ministry of Education, Ocean University of China, Qingdao, China	3	39	0
Laboratory of Environmental Microbiology and Ecology (LEnME), Department of Life Science, National Institute of Technology, Rourkela, Odisha 769 008, India	4	56	0
School of Environmental Science and Engineering, Shandong University, Jinan, Shandong 250100, China	3	29	0

more documents.

3.8. Trends of topics

The trend of topics by year is shown in Figure 12. Keywords plus are selected based on a minimum frequency of 20. Accordingly, with 601 frequencies in 2015, the keyword Biodegradation was the highest, and then with a frequency of 492 in 2016, the keyword Bioremediation was determined. Moreover, keywords, such as Gene sequence[30], Gasoline[31], Microflora[32], Wastewater treatment[33-35], and Microbiota[36] in 2019 were identified with frequencies of 36, 32, 27, 26, and 25, respectively.

3.9. Tree-fields Plot

The relationship between author's keywords and sources is shown in Figure 13. Larger squares in each row represent the largest value relative to their peers. For example, Cappello (author) mentioned more bioremediation keyword in his documents[37-43], while others used the marine environment keyword more in their documents[10,39,41,42,44,45-55].

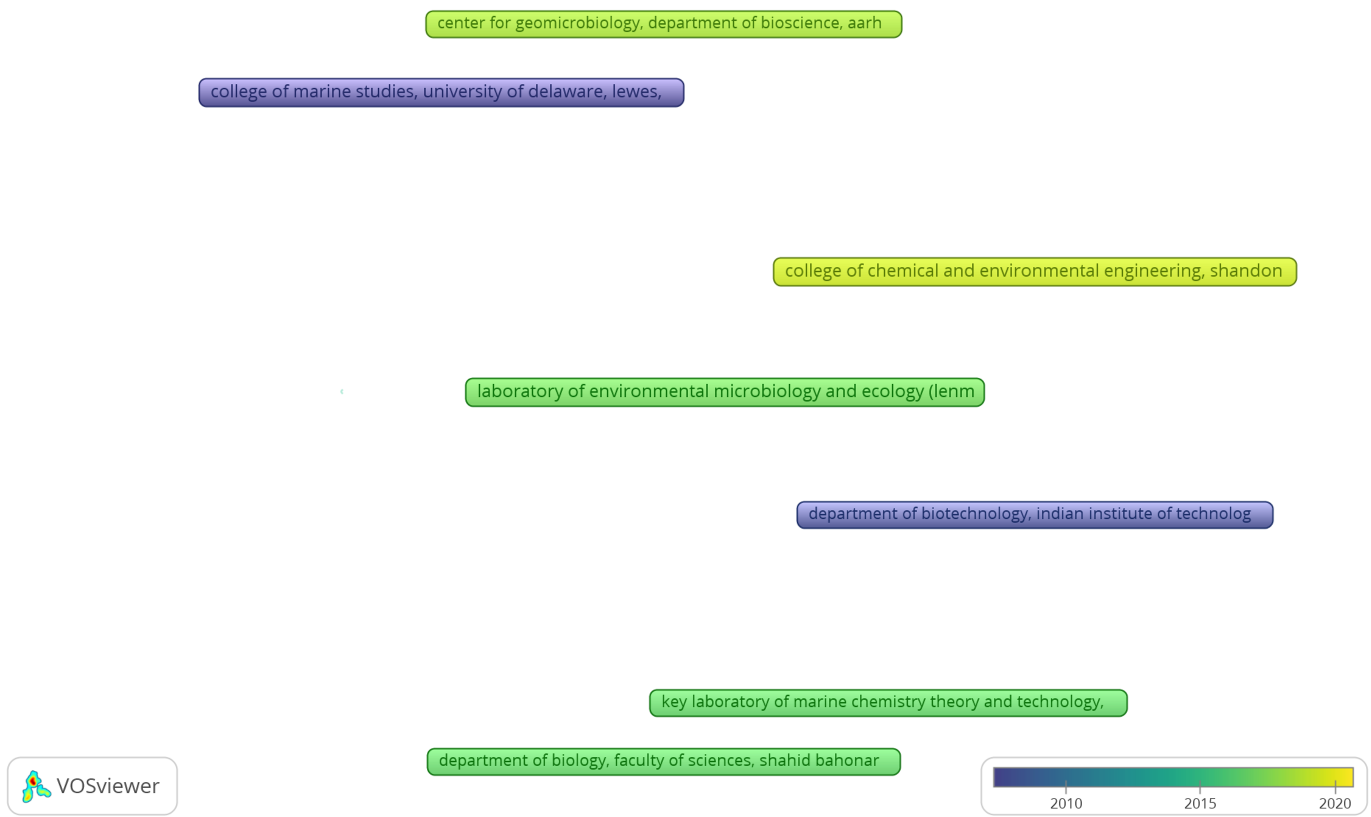

Figure 9. Categorize organizations by year

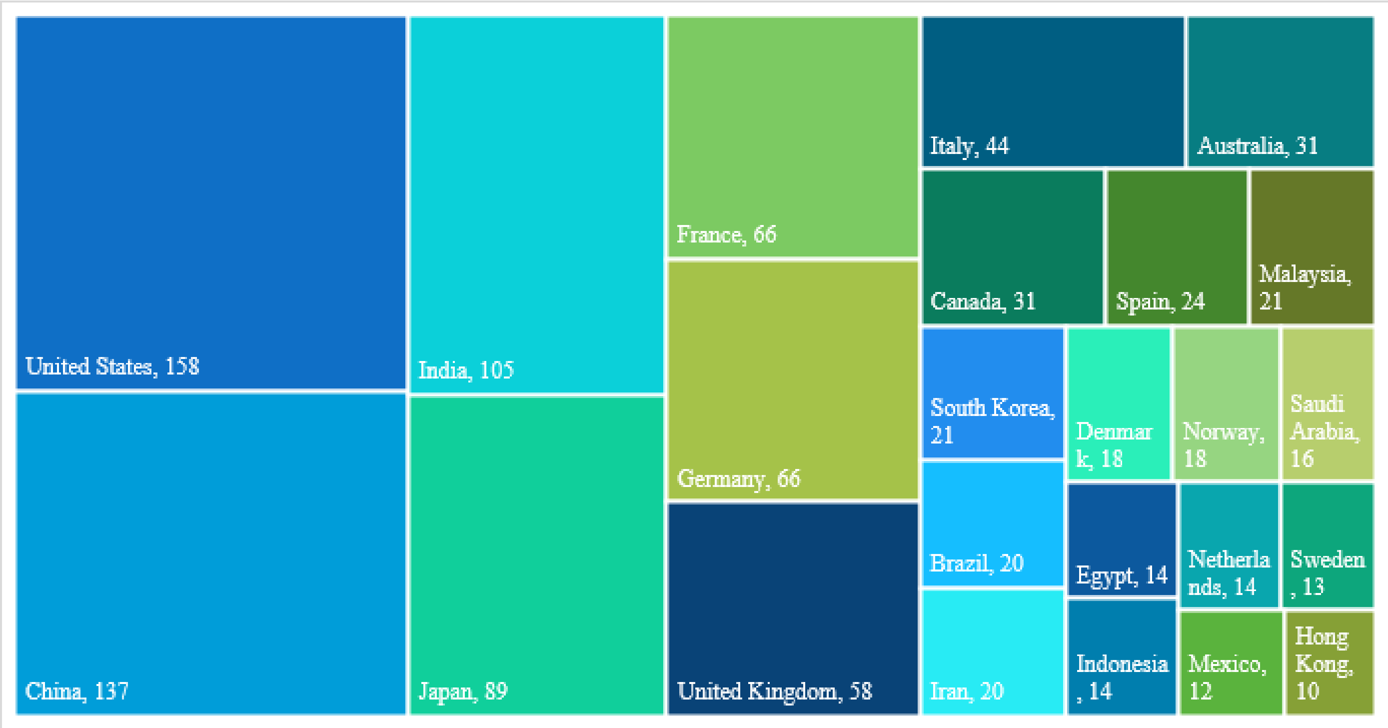

Figure 10. Chart of countries with at least 10 documents published in Scopus

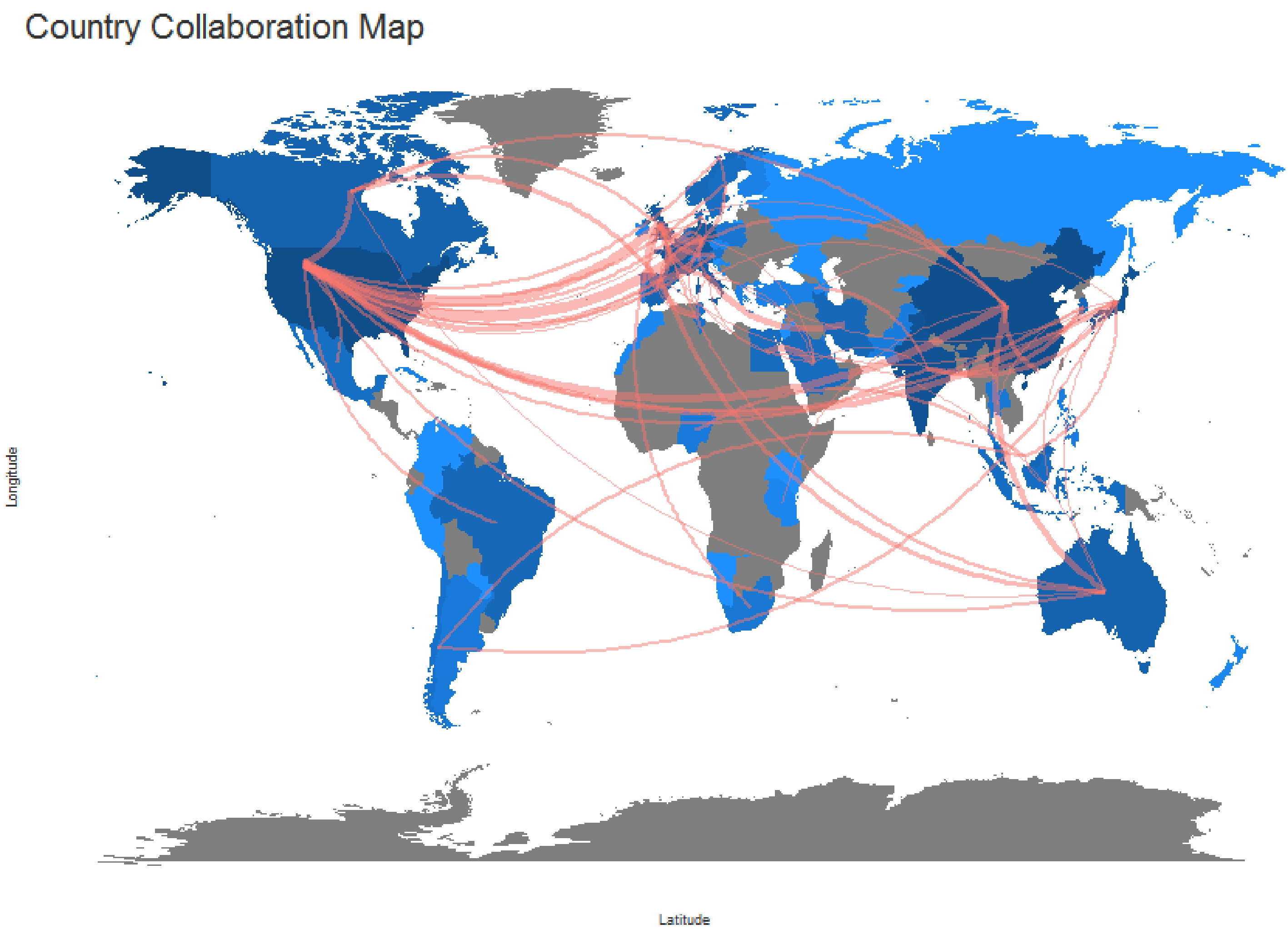

Figure 11. Country collaboration map

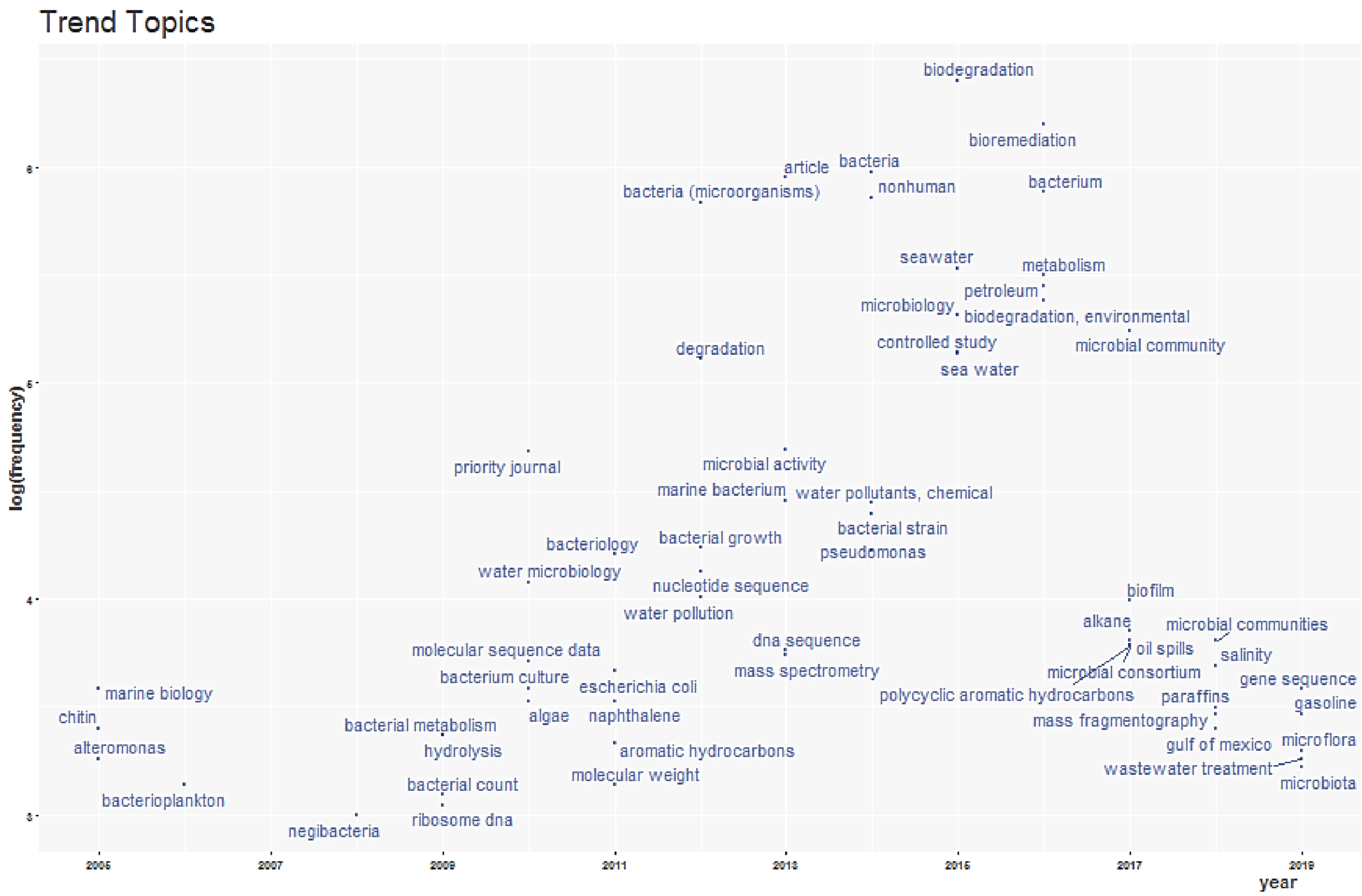

Figure 12. Trends of topics

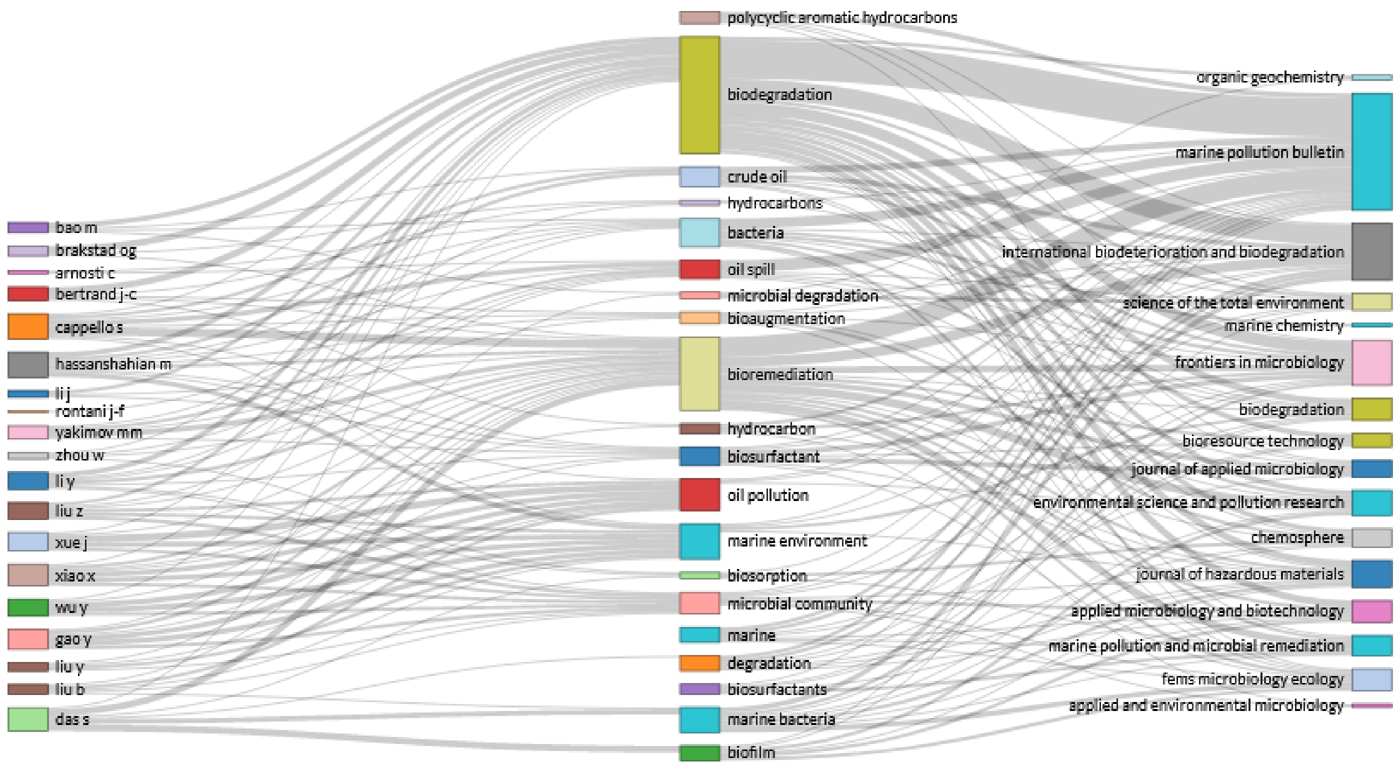

Figure 13. Tree-fields Plot. Author name (left), keyword (middle) and source (right)

4. Conclusion

The elimination of contamination from marine environments by bacteria has been interested for researchers at past 35 years and it is likely to continue in the coming years. According to the results of this study, at least 24 countries are researching this issue, but the relationship and cooperation between research organizations are low. Therefore, increasing cooperation between countries and organizations in the future is recommended. Regarding the results of the trend in 2019, it is likely that future research will focus on the use of microflora in water treatment.

Declarations

Competing interests

No potential competing interest was reported by the authors.

Authors' contribution

All authors were involved in interpretation and data collection, design of the article, review, and manuscript preparation.

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Ethical considerations

The authors checked for plagiarism and consented to the publishing of the article. The authors have also checked the article for data fabrication, double publication, and redundancy.

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